

# The 17 MeV Anomaly in Beryllium Decays and $U(1)$ Portal to Dark Matter

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## Abstract

The experiment of Krasznahorkay *et al* observed the transition of a  $^8\text{Be}$  excited state to its ground state and accompanied by an emission of  $e^+e^-$  pair with 17 MeV invariant mass. This  $6.8\sigma$  anomaly can be fitted by a new light gauge boson. We consider the new particle as a  $U(1)$  gauge boson,  $Z'$ , which plays as a portal linking dark sector and visible sector. In particular, we study the new  $U(1)$  gauge symmetry as a hidden or non-hidden group separately. The generic hidden  $U(1)$  model, referred to as dark  $Z$  model, is excluded by imposing various experimental constraints. On the other hand, a non-hidden  $Z'$  is allowed due to additional interactions between  $Z'$  and Standard Model fermions. We also study the implication of the dark matter direct search on such a scenario. We found the search for the DM-nucleon scattering excludes the range of DM mass above 500 MeV. However, the DM-electron scattering for MeV-scale DM is still allowed by current constraints for non-hidden  $U(1)$  models. It is possible to test the underlying  $U(1)$  portal model by the future Si and Ge detectors with  $5e^-$  threshold charges.

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## I. INTRODUCTION

Recently, the experiment of Krasznahorkay *et al.* studied the decays of a  $^8\text{Be}$  excited state to its ground state and found a bump in both the opening angle and invariant mass distributions of  $e^+e^-$  pairs produced in the transitions [1]. This  $6.8\sigma$  deviation from the expectation can be fitted by the production of a new particle  $X$  of mass around 17 MeV in the transition  $^8\text{Be}^* \rightarrow ^8\text{Be} X$  and the subsequent decay of  $X$  into electron-positron pair. Although the excess can be due to unknown nuclear effects, the existence of a new particle was investigated in [2–11] from different aspects. It is shown that the proton coupling to  $X$  is suppressed, or the  $X$  boson is *protophobic*, in order to alleviate various experimental constraints for a new light gauge boson [2, 7]. Some anomaly free phenomenological models are also proposed in Refs. [3, 7]. Furthermore, simple models involving new scalar or pseudo-scalar particles are excluded as shown in Ref. [7].

In this paper, we take the new particle as a  $Z'$  gauge boson corresponding to a new  $U(1)_d$  gauge symmetry. The charge  $d$  can be a completely hidden quantum number governing the dark sector or a certain combination of Standard Model (SM) quantum numbers. Hence the  $Z'$  boson plays as a portal between the dark sector and visible sector. A simple dark photon model containing two parameters  $(\varepsilon, m)$  has been ruled out by confronting various experiments both in quark sector and lepton sector [2]. The dark  $Z$  model, however, has one more parameter  $\varepsilon_Z$  which is induced by the mass mixing between  $Z$  and  $Z'$ . This mixing allows interactions between  $Z'$  and fermions including neutrinos. Then it is a natural and interesting topic to discuss the possibility of this more generic model. In the following sections, we will show that the hidden gauge boson couples to proton (neutron) and electron (neutrino) in equal strengths. Due to the above coupling relations, we will present explicitly the incompatibility between the measurement of Krasznahorkay *et al.* [1] and TEXONO  $\nu$ –electron scattering experiments [12]. Since the generic hidden  $U(1)$  model is disfavored, we also consider non-hidden  $U(1)$  portal models for further phenomenological studies. We shall demonstrate that such models are also disfavored by the existing DM direct search data for DM mass above 500 MeV. To probe DM lighter than 500 MeV in non-hidden models, we propose direct searches based upon DM-electron scatterings.<sup>1</sup>

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<sup>1</sup> A similar idea for scalar and vector DM was investigated in Ref. [8]. Here we focus on fermionic DM with a p-wave contribution to DM annihilation cross section during thermal freeze-out epoch.

We organized the paper as follows : in section II we describe the generic  $Z'$  Lagrangian and take the  $Z'$  boson as the DM force mediator; in section III we derive the constraints for the model parameters from the  $^8\text{Be}$  transition and other experiments, in particular TEXONO experiment excludes the simple dark  $Z$  model; in section IV we investigate the implications of DM direct search with DM-nucleus scatterings and discuss the sensitivities of future Si and Ge detectors to DM-electron scattering in the framework of non-hidden  $U(1)$  portal model with the WIMP mass between 20 MeV and 500 MeV; we then conclude in Section V.

## II. THE FRAMEWORK

### A. The generic hidden $U(1)$ model

We assume that the dark sector interacts among themselves and links the SM particles via a hidden abelian  $U(1)_d$  gauge symmetry. The connection between visible and dark sector is established by the  $U(1)_d$  gauge boson  $Z'$  through its kinetic mixing with the SM  $U(1)$  gauge boson  $B$ ,

$$\mathcal{L}_{\text{gauge}} = -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \frac{1}{2}\frac{\varepsilon}{\cos\theta_W}Z'_{\mu\nu}B^{\mu\nu} - \frac{1}{4}Z'_{\mu\nu}Z'^{\mu\nu}, \quad (1)$$

where  $\varepsilon$  characterizes the mixing. The massive gauge bosons  $Z$  and  $Z'$  obtain their masses after spontaneous symmetry breaking as well as a further rotation between them. Hereafter for simplicity we keep the same notation  $Z'$  to denote the gauge boson of  $U(1)_d$  in mass eigenstate. Without loss of generality, the interaction among  $Z'$  and SM fermions can be described phenomenologically as

$$\mathcal{L}_{\text{visible}} = -\left(\varepsilon_\gamma e J_{\text{em}}^\mu + \varepsilon_Z \frac{g}{2c_W} J_{\text{NC}}^\mu\right) Z'_\mu \quad (2)$$

where  $\varepsilon_\gamma = \varepsilon$ , and  $\varepsilon_Z$  is some certain combination of  $\varepsilon$  and rotation angles, which also depends on UV complete theory and mass generation mechanism. The electromagnetic current and weak neutral current are

$$J_{\text{em},f}^\mu = Q_f \bar{f} \gamma^\mu f \quad \text{and} \quad J_{\text{NC},f}^\mu = (T_{3f} - 2Q_f s_W^2) \bar{f} \gamma^\mu f - T_{3f} \bar{f} \gamma^\mu \gamma_5 f \quad (3)$$

respectively, where  $f$  stands for the fermions with corresponding electric charge  $Q_f$ , isospin  $T_{3f} = \pm\frac{1}{2}$ . More details about this model can be found in [13, 14]. Furthermore, we assume

the interaction in dark sector is

$$\mathcal{L}_{\text{dark}} = e_d \bar{\chi} \gamma^\mu \chi Z'_\mu, \quad (4)$$

where the DM  $\chi$  is assumed to be Dirac fermion carrying a charge  $e_d$  under the hidden gauge symmetry.

### B. $Z' \rightarrow e^+ e^-$ and $Z' \rightarrow \nu \bar{\nu}$

In fitting to the measurement by Krasznahorkay *et al.*, one obtains the mass of the light boson to be [1]

$$M_{Z'} = 16.7 \pm 0.35(\text{stat.}) \pm 0.5(\text{sys.}) \text{ MeV}. \quad (5)$$

Therefore, the  $Z'$  considered in our framework can only decay into  $e^+ e^-$  and  $\nu \bar{\nu}$ . The corresponding decay widths are given by

$$\Gamma(Z' \rightarrow e^+ e^-) = \alpha_{\text{em}}(a_e^2 + b_e^2) \frac{M_{Z'}^2 + 2m_e^2}{3M_{Z'}} \sqrt{1 - \frac{4m_e^2}{M_{Z'}^2}} \quad (6)$$

and

$$\Gamma(Z' \rightarrow \nu_i \bar{\nu}_i) = \alpha_{\text{em}}(a_\nu^2 + b_\nu^2) M_{Z'} \quad (7)$$

respectively<sup>2</sup>. We have summed up three flavors of neutrino and the parameters  $a_f$  and  $b_f$  are defined as

$$a_f = Q_f \varepsilon_\gamma + \frac{T_{3f} - 2Q_f s_W^2}{2c_W s_W} \varepsilon_Z \quad \text{and} \quad b_f = -\frac{T_{3f}}{2c_W s_W} \varepsilon_Z. \quad (8)$$

Numerically, we have  $a_e = -\varepsilon_\gamma - 0.05\varepsilon_Z$ ,  $b_e = -0.6\varepsilon_Z$  and  $a_\nu(b_\nu) = -(+ )0.6\varepsilon_Z$  respectively.

## III. THE CONSTRAINTS IN GENERIC HIDDEN $U(1)$ MODEL

### A. The explanation to ${}^8\text{Be}^* \rightarrow {}^8\text{Be} Z'$ and other experimental constraints

The dark  $Z'$  interaction with nucleon can be characterized as

$$-\mathcal{L}_N = Z'^\mu (J_\mu^N + J_{5\mu}^N) \quad (9)$$

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<sup>2</sup> One should bear in mind that a dark sector decay channel may also open for the corresponding final state particle mass is kinematically allowed. Hence the branching ratio of  $Z' \rightarrow e^+ e^-$  could be a tuning parameter.

with  $J_\mu^N = e\varepsilon_p \bar{p}\gamma_\mu p + e\varepsilon_n \bar{n}\gamma_\mu n$  and  $J_{5\mu}^N = e\varepsilon_{p5} \bar{p}\gamma_\mu \gamma_5 p + e\varepsilon_{n5} \bar{n}\gamma_\mu \gamma_5 n$  respectively. Only the vector current part contributes to the matrix element  $\langle {}^8\text{Be}Z' | \mathcal{L}_N | {}^8\text{Be}^* \rangle$  if parity is conserved. It is interesting that the couplings for proton and neutron are identical to  $a_e$  and  $a_\nu$  except the sign flip by opposite electric charge and weak isospin. Thus, we deduce that

$$\varepsilon_p = 2a_u + a_d = \varepsilon_\gamma + 0.05\varepsilon_Z = -a_e \quad (10a)$$

$$\varepsilon_n = a_u + 2a_d = -0.6\varepsilon_Z = -a_\nu. \quad (10b)$$

According to Refs. [1, 2], we have

$$\frac{\Gamma({}^8\text{Be}^* \rightarrow {}^8\text{Be}Z')}{\Gamma({}^8\text{Be}^* \rightarrow {}^8\text{Be}\gamma)} Br(Z' \rightarrow e^+e^-) = 5.8 \times 10^{-6}. \quad (11)$$

In the isospin symmetry limit<sup>3</sup>, we have [2]

$$\frac{\Gamma({}^8\text{Be}^* \rightarrow {}^8\text{Be}Z')}{\Gamma({}^8\text{Be}^* \rightarrow {}^8\text{Be}\gamma)} = (\varepsilon_p + \varepsilon_n)^2 \left[ 1 - \left( \frac{M_{Z'}}{18.15 \text{ MeV}} \right)^2 \right]^{3/2}. \quad (12)$$

The branching ratio of  $Z' \rightarrow e^+e^-$  in our scenario can be deduced from Eq. (6) and Eq. (7),

$$Br(Z' \rightarrow e^+e^-) \approx \frac{a_e^2 + b_e^2}{(a_e^2 + b_e^2) + 3(a_\nu^2 + b_\nu^2)} = \frac{\varepsilon_p^2 + \varepsilon_n^2}{\varepsilon_p^2 + 7\varepsilon_n^2}, \quad (13)$$

where we have applied the relations  $|b_e| = |b_\nu| = |a_\nu| = |\varepsilon_n|$ ,  $|a_e| = |\varepsilon_p|$ , which particularly hold in dark  $Z$  model.

In addition, as pointed in Ref. [2] and constraints summarized in Ref. [15], two most severe bounds from the search of dark photon in the relevant mass range are obtained by NA48/2 [16] and E141 experiments [17]. NA48/2 gives an upper bound requiring  $\varepsilon_{\text{max}} \lesssim 4.8 \times 10^{-4}$  at 90% C.L. [16]. We translate the constraint into our framework by interpreting the process as  $\pi^0 \rightarrow Z'\gamma \rightarrow e^+e^-\gamma$ . Again the branching ratio modification is taken into account,

$$|\varepsilon_p| \lesssim \frac{(0.8 - 1.2) \times 10^{-3}}{\sqrt{Br(Z' \rightarrow e^+e^-)}}. \quad (14)$$

E141 is a electron beam dump experiment at SLAC which searches for a dark photon bremsstrahlung resulting from electrons incident on a nuclear target [17]. The experiment sets a lower bound for the coupling strength in our scenario

$$\frac{|a_e|}{\sqrt{Br(Z' \rightarrow e^+e^-)}} \gtrsim 2 \times 10^{-4}. \quad (15)$$

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<sup>3</sup> In general the transitions between  ${}^8\text{Be}^*$  and  ${}^8\text{Be}$  can be both isovector and isoscalar. A isospin breaking derivation for the transition is presented in Ref. [2]. However, the modification is only about 20%. Since our results are not much affected, we present the isospin symmetry limit of the transition rate for simplicity.

Combining the condition of Eq. (12) and two constraints, Eq. (14) and Eq. (15), we plot the allowed parameter region for  $(\varepsilon_p, \varepsilon_n)$  in Figure 1. The green band is the allowed region to fit the  $^8\text{Be}$  anomaly while the purple shaded and pink shaded areas are excluded by the beam dump and NA48/2 experiments, respectively. One observes that  $\varepsilon_n$  lies within a narrow region between  $10^{-1}$  and  $10^{-2}$  and  $\varepsilon_p$  is constrained in the range of  $10^{-4} \sim 10^{-3}$ . The allowed coupling strength of  $Z'$  to proton is relatively smaller than the coupling strength of  $Z'$  to neutron. Hence a *protophobic* feature is suggested by the measurement of Krasznahorkay *et al.*.

### B. $\nu - e$ scattering experimental constraint

For the hidden  $U(1)$  model, the same constraints also apply to  $(a_e, a_\nu)$  as shown in Eq. (10a) and Eq. (10b). Therefore, the constraints from short baseline accelerator and/or reactor neutrino-electron scattering experiments must be taken into account [12, 18, 19]. A global analysis on the nonstandard interactions that are deviated from the SM predictions is presented in Ref. [20]. We take the effective Lagrangian approach by integrating the intermediate  $Z'$  boson, which yields the following bounds

$$|(a_e - a_\nu)a_\nu| \lesssim 8 \times 10^{-9} \quad \text{and} \quad |(a_e + a_\nu)a_\nu| \lesssim 5 \times 10^{-9} \quad (16)$$

Using Eqs. (10a) and (10b), these bounds can be translated into constraints for  $\varepsilon_p$  and  $\varepsilon_n$ . These constraints are so stringent that they are incompatible with the experimental constraints we just derived in the framework of generic hidden  $U(1)$  model.

## IV. NON-HIDDEN $U(1)$ PORTAL AND DM-ELECTRON SCATTERING PROCESS

To accommodate the new light gauge boson indicated in  $^8\text{Be}$  anomaly as well as  $U(1)$  portal scenario, we are led to consider models with non-hidden  $U(1)$  gauge symmetry and MeV-scale DM<sup>4</sup>. Non-hidden  $U(1)$  charge suggests a certain linear combination of SM quantum number and/or other hidden charge. Phenomenologically, such models will include a

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<sup>4</sup> An axion-like or other scenario of  $m_\chi < 500$  MeV are viable. We concentrate our discussion on MeV-scale DM in this paper.

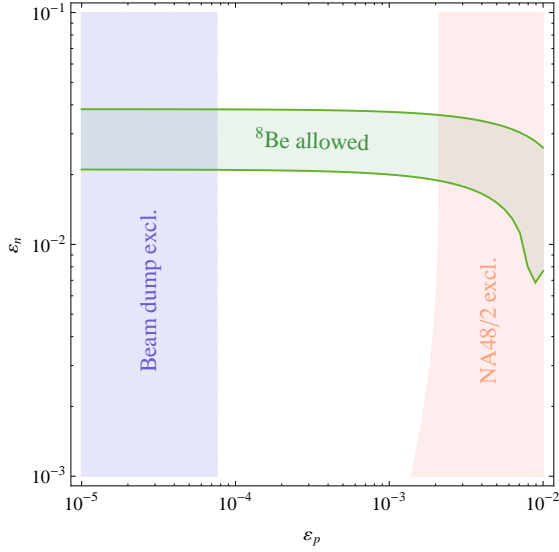


FIG. 1: The allowed parameter space on  $(\varepsilon_p, \varepsilon_n)$  or  $(a_e, a_\nu)$  plane in generic hidden  $U(1)$  model. E141 and NA48/2 exclusion regions are indicated. The green band is the allowed parameter space resulting from  $^8\text{Be}$  anomaly with the error of  $Z'$  mass taken into account. The allowed narrow band is however incompatible with the TEXONO  $\nu - e$  scattering experiment [12].

new set of direct gauge-fermion couplings. The interplay between these couplings with the gauge boson mixings will modify the relations among quark and lepton couplings such as Eq. (10a) and Eq. (10b). There are various ways of model-building to impose such non-hidden  $U(1)$  gauge symmetry motivated by  $^8\text{Be}$  anomaly [3, 7]. In this paper, we do not intend to study these models in detail but rather assume that the couplings of  $Z'$  to various fermions are not correlated. In particular, we assume the severe constraint from  $\nu - e$  scattering can be alleviated<sup>5</sup>. In this section, we first discuss various constraints on those generic non-hidden  $U(1)$  models, including constraints from cosmology and constraints from DM direct search with DM-nucleus scattering. We then discuss the sensitivities of future Si and Ge detectors to DM-electron scatterings for light DM in the MeV mass range.

<sup>5</sup> One simple example is the  $U(1)_B$  model with  $B$  the baryon number. In such a model the neutrino- $Z'$  coupling vanishes, thus the TEXONO bounds can be evaded. An anomaly free  $U(1)_B$  model is proposed in Ref. [7]

### A. Thermal freeze-out and cosmological constraints

DM relic abundance requires the WIMP annihilation cross section to be around  $\langle\sigma v\rangle \approx 3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1}$ . In our study we shall consider other cosmological constraints on  $\langle\sigma v\rangle$ . For cosmic microwave background (CMB) the additional injection of energy via the DM annihilations will increase the ionization fraction on the CMB anisotropy. Hence it will suppress the power spectrum at small angular scales due to the broadening of the last scattering surface, and also enhance the polarization power spectra at low multipoles due to the increasing probability of the Thomson scattering. The Planck data puts strong bounds on s-wave annihilation cross section for the DM mass in a range of sub-MeV to 100 GeV [25]. In particular, the constraints are stringent if the fraction of electron final state is non-negligible. We note that the  $^8\text{Be}$  anomaly indicates a substantial fraction of  $e^+e^-$  final state in  $Z'$  decays. In such a case the Planck data sets the limits of s-wave  $\langle\sigma v\rangle < 10^{-29} \sim 10^{-30} \text{ cm}^3 \text{ s}^{-1}$  for MeV-scale DM [25]. Therefore, we consider the process,  $\chi\chi \rightarrow Z'Z'$ , as the DM annihilation channel in this scenario. In the parity conservation limit, this process is mostly p-wave as pointed out in [26]. We include the Sommerfeld enhancement factor [27, 28] and find  $\alpha_d = e_d^2/4\pi$ , the analogous fine structure constant for  $U(1)_d$  gauge interaction, is about  $5.2 \times 10^{-5} (m_\chi/\text{MeV})$  to satisfy the thermal relic abundance. Finally, in order to prevent the photodissociation to alter the light element abundances during the big bang nucleosynthesis, one requires the lifetime of  $Z'$  to be less than 1 second in the early universe [29]. The mixing parameter is constrained to be  $\varepsilon_Z \gtrsim 6.8 \times 10^{-11} \times \sqrt{17\text{MeV}/m_{Z'}}$  [30]. In this paper, we focus on the range that  $m_\chi > M_{Z'}$  and make a threshold cut at  $m_\chi = 20 \text{ MeV}$  for the study of DM-electron scattering process.

### B. Direction search bounds on DM-nucleon cross section through the exchange of 17 MeV $Z'$

In the limit of zero momentum transfer ( $q^2 = 0$ ), the DM-nucleus scattering cross section is given by

$$\sigma_{\chi A} = \frac{16\pi\alpha_{\text{em}}\alpha_d\mu_{\chi A}^2}{m_{Z'}^4}[\varepsilon_p Z + \varepsilon_n(A - Z)]^2 \quad (17)$$

where  $Z$  and  $A$  are proton number and mass number, respectively, and  $\mu_{\chi A} = m_\chi m_A / (m_\chi + m_A)$  is the DM-nucleus reduced mass. In this case, DM-neutron cross section  $\sigma_{\chi n}$  is the main



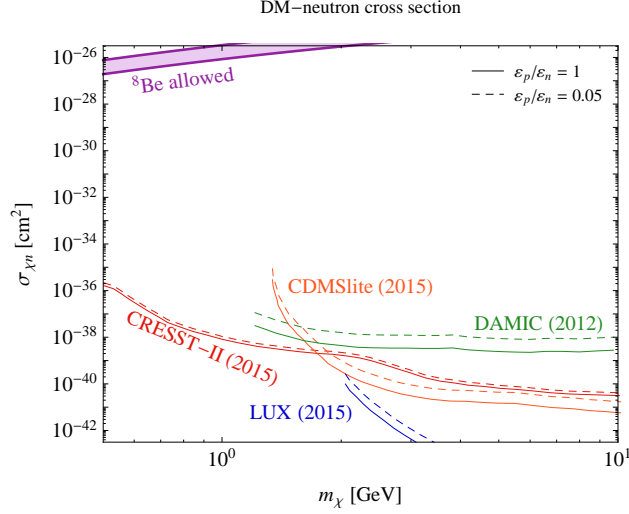


FIG. 2: The theoretical predictions of  $\sigma_{\chi n}$  from the allowed range of  $(\epsilon_p, \epsilon_n)$  parameter space is shown. The purple shaded regions are the predicted DM-neutron cross section. The exclusion lines by CRESST-II(2015) [21], DAMIC(2012) [22], CDMSlite(2015) [23], and LUX(2015) [24] are presented for  $\epsilon_p/\epsilon_n = 1$  and  $\epsilon_p/\epsilon_n = 0.05$ , respectively, where the latter ratio is the protophobic scenario favored by  $^8\text{Be}$  experiment. It can be seen that the DM direct search excludes DM down to  $m_\chi = 500$  MeV for both  $\epsilon_p/\epsilon_n$  ratios.

contribution to  $\sigma_{\chi A}$ , while DM-proton cross section  $\sigma_{\chi p}$  is suppressed by the factor  $\epsilon_p^2/\epsilon_n^2$ . Additionally, the force mediator is light enough such that a suppression factor  $m_{Z'}^4/(m_{Z'}^2 + q^2)^2$  due to the momentum transfer should be included in the propagator. For a single nucleon,  $q \sim \mathcal{O}(1 \text{ MeV})$  when  $m_\chi \sim 1 - 100 \text{ GeV}$  from the halo DM. In our analysis, we consider this momentum suppression in the calculation of  $\sigma_{\chi n, p}$ . We found that the predicted DM-nucleon cross section based upon the allowed range of  $(\epsilon_p, \epsilon_n)$  is far beyond the current DM direct search constraints.

We show in Fig. 2 the theoretical predictions of  $\sigma_{\chi n}$  for DM mass between 0.5-10 GeV. The corresponding DM direct search bounds obtained by CRESST-II(2015) [21], DAMIC(2012) [22], CDMSlite(2015) [23], and LUX [24]<sup>6</sup> are also shown. For DM mass higher than 10 GeV, the direct searches give even more stringent bounds. It is seen that the

<sup>6</sup> A new update result of LUX on IDM 2016 claims a constraint four times better than the one published in 2015 during the writing of this paper. By incorporating this new result, the exclusion region will extend to a lower DM-nucleon cross section. Nonetheless, we still present the LUX 2015 result as a benchmark in this work.

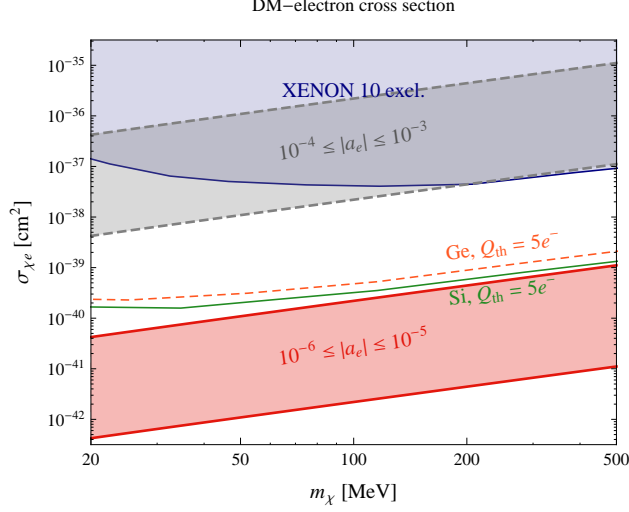


FIG. 3: The red shaded regions are the theoretical predictions of  $\sigma_{\chi e}$  with  $|a_e|$  lying in the range of  $10^{-6} - 10^{-5}$  for  $20 \text{ MeV} < m_\chi < 500 \text{ MeV}$ . The gray shaded region are the predictions with  $|a_e|$  lying in the range of  $10^{-4} - 10^{-3}$ . XENON 10 [35] excludes the parameter space of  $|a_e| > 10^{-4}$  for  $m_\chi > 200 \text{ MeV}$ . The projected sensitivities of Si and Ge detectors with threshold charges of  $5e^-$  are represented by the green solid line and the orange dashed line, respectively.

predicted  $\sigma_{\chi n}$  based upon the allowed parameter region as indicated in Fig. 1 is excluded. Therefore, the DM direct searches also disfavor the non-hidden  $Z'$  model for the DM mass above 500 MeV. In other words, for this range of DM mass, the current DM direct search bounds are incompatible with the parameter space derived from  $^8\text{Be}$  anomaly.

### C. DM-electron scattering process

The conventional DM direct search looks for the nuclear recoils. However, the nuclear recoil energy,  $E_{\text{recoil}} = (m_\chi v)^2 / (2m_A) \approx (m_\chi / 100 \text{ MeV})^2 (m_A / 10 \text{ GeV})^{-1} \text{ eV}$ , is sub-eV for the MeV-scale DM and is far below the threshold energies in current experiments.<sup>7</sup> Instead of detecting the nuclear recoils, it was suggested to detect the DM-electron scattering as the DM signal [31–33]. The DM-electron cross section  $\sigma_{\chi e}$  is given by [34]

$$\sigma_{\chi e} = 16\pi\alpha_{\text{em}}\alpha_d a_e^2 \frac{\mu_{\chi e}^2}{M_{Z'}^4} \quad (18)$$

<sup>7</sup>  $v \simeq 10^{-3}$  is the DM velocity dispersion in the halo.

where  $\mu_{\chi e}$  is the DM-electron reduced mass. We show the theoretical predictions on  $\sigma_{\chi e}$  and XENON 10 exclusion region in Fig. 3. The blue shaded area is excluded by XENON 10 based on the DM-electron scattering and the capability of charge threshold  $Q_{\text{th}} = 10e^-$  [35]. It can be seen that  $|a_e| \geq 10^{-4}$  is excluded for  $m_\chi > 200$  MeV. The projected sensitivities for silicon and germanium targets with improved  $Q_{\text{th}} = 5e^-$  are presented as green solid line and orange dashed line, respectively [36]. The red shaded region is the theoretical predictions of  $\sigma_{\chi e}$  corresponding to the range of  $10^{-6} < |a_e| < 10^{-5}$ .  $m_\chi$  is taken to be between 20 MeV and 500 MeV where 20 MeV roughly corresponds to the DM mass lower bound for the annihilation  $\chi\chi \rightarrow Z'Z'$  to take place while 500 MeV is the energy threshold for DM direct search with DM-nucleon scattering. Our calculation on  $\sigma_{\chi e}$  shows that the MeV DM under  $Z'$  model can be tested by future experiments.

## V. SUMMARY

Motivated by the possible existence of a new light boson from the experiment of Krasznahorkay *et al.* [1], we investigate the  $Z'$ -portal models. The additional  $U(1)$  gauge symmetry may correspond to a hidden charge or a non-hidden charge. The reactor neutrino-electron scattering sets a severe constraint which excludes the parameter space of generic hidden  $U(1)$  model. Since the generic hidden  $U(1)$  model is disfavored, we are led to considering non-hidden  $U(1)$  portal models. Using the current DM direct search data, we have shown that such models are also disfavored for DM mass larger than 500 MeV. To probe DM lighter than 500 MeV in non-hidden  $U(1)$  models, we propose direct searches based upon DM-electron scatterings. The sensitivities of future Si and Ge detectors to  $\sigma_{\chi e}$  are given in Fig. 3. Hence the sensitivities of these detectors to the couplings strength  $|a_e|$  can be determined accordingly.

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